P120

Heterogeneous ferromagnetic state in small particles and its connection with ferroelectricity

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Phase transitions in spherical particles of a cubic ferromagnetic were considered in the framework of the Ginzburg-Landau phenomenological theory. Concentrating on depolarizing field effects, we study the competition between states with homogeneous magnetization and vortex structures. For large sphere radii ($R>R_c$), a phase transition to a vortex state is possible, while for $R<R_c$ it can be in a homogeneous state. We obtain the inhomogeneous distribution of the ferromagnetic order parameter in the form of 2D and 3D vortices, for which the absolute value of the local magnetization depends on the distance from the center of the vortex. This approach has meaning for mesoscopic-sized particles. Such softening of the amplitude variations of magnetization was considered, for example, in the papers of Levanyuk [1] in the analysis of the ferroelectric near the phase transition and the Robler et al. [2] in the analysis of the ferromagnet near the phase transition.

It is known that there is a connection between magnetic frustration and ferroelectricity in multiferroics [3]. In multiferroics, the simultaneous existence of magnetic and electric dipoles does not always cause a strong connection between them, since the microscopic mechanisms of ferroelectricity and magnetism are different. A probable microscopic mechanism inducing ferroelectricity in magnetic spirals was discussed, for example, in reference [4]. It involves the antisymmetric Dzyaloshinsky–Moriya (DM) interaction. The DM interaction causes a non-collinear spin ordering. If the magnetic ordering is inhomogeneous, it can lead to polarization [3, 5]. In our work, we compute the polarization caused by ferromagnetic 2D and 3D vortices within the phenomenological approach. The results are used to discuss the formation of "polar clusters".

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